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CREEP BEHAVIOR OF UTAH OIL SHALE SUBJECT TO UNIAXIAL LOADING

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REPORT OF INVESTIGATIONS

CREEP BEHAVIOR OF UTAH OIL SHALE SUBJECT TO UNIAXIAL LOADING

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CREEP BEHAVIOR OF UTAH OIL SHALE SUBJECT TO UNIAXIAL LOADING[a]

By

Ken P. Chong[1], George F. Dana[2] and Jui-Lin Chen[3]

ABSTRACT

This paper presents results of a study on the creep behavior of Utah oil shale. A Conbel Model 355 pneumatic driven testing machine is used. The set of duplicate test specimens required for creep testing were cut from a single oil shale layer using a wire saw to avoid any surface damage. A rheological model was developed for creep behavior of oil shale as a function of stress level and organic content. Data from creep testing and Fischer assay analyses were used to demonstrate correlation between various stress levels and organic contents for samples taken from the Mahogany Zone of the Parachute Creek Member in Utah's Cowboy Canyon.

INTRODUCTION

Oil shale resources in the United States are important as an alternative energy source. Although a number of development procedures are being investigated, the need to modify the rock during mining or in-place is common to all of them. Knowledge of the mechanical properties of oil shale is essential to any form of development, including room-and-pillar mine design. One of these mechanical properties of oil shale is its creep behavior.

In this paper, uniaxial creep tests were performed to investigate the effects of different stress levels and organic contents on the creep behavior of oil shale. Each set of test specimens was prepared from a single layer of oil shale. The lateral homogeneity of oil shale (7) insures that the sets were duplicate samples. All specimens were cut perpendicular to the bedding planes. Statistical analysis indicates

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that the creep properties of oil shale are strongly dependent on organic contents and various stress levels.

THEORETICAL CONSIDERATIONS

The objective of this section is to provide the theoretical background and the type of rheological model (1, 5, 6, 8, 9) used. Oil shale is nearly linear elastic under small strains as measurements of load-displacement relationship reveal (2, 3, 4). However under constant loading it creeps slightly. Thus the model that was chosen is for the materials which retains initial linearity between load and deflection and a non-linear relationship depending on time.

Based on the observation of the raw data on ε vs time plots (Fig. 1) the following nonlinear model (8) is used:

$$\varepsilon\ (O_c, S, t) = \varepsilon^\circ(O_c, S) + \varepsilon^+\ (O_c, S)\ t^n \quad . \ . \ . \ . \ . \ . \ . \ . \ . \quad (1)$$

where, ε = total strain perpendicular to bedding planes = ε_{33};

ε° = initial strain;

ε^+ = creep related strain;

t = non-dimensionalized time;

O_c = organic content expressed as a volume fraction;

S = stress level expressed as a fraction of ultimate stress; and

n = coefficient depending on O_c and S.

To determine the functions ε°, ε^+ and n, the following procedure is used:

Taking the logarithms of Eq. (1) yields

$$\log\ (\varepsilon - \varepsilon^\circ) = \log \varepsilon^+ + n \log t \quad . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \quad (2)$$

Fig. 2 shows a typical plot of $\log\ (\varepsilon - \varepsilon^\circ)$ versus $\log\ t$ resulting in a straight line with slope n and the intercept at unit time is ε^+. On the other hand, ε° is the intercept at 0 time taken from Fig. 1.

Based on the present uniaxial testing, a nonlinear pseudo 3-D creep model can be constructed, relating the strains to stresses.

For pure axial compression, the stress tensor is

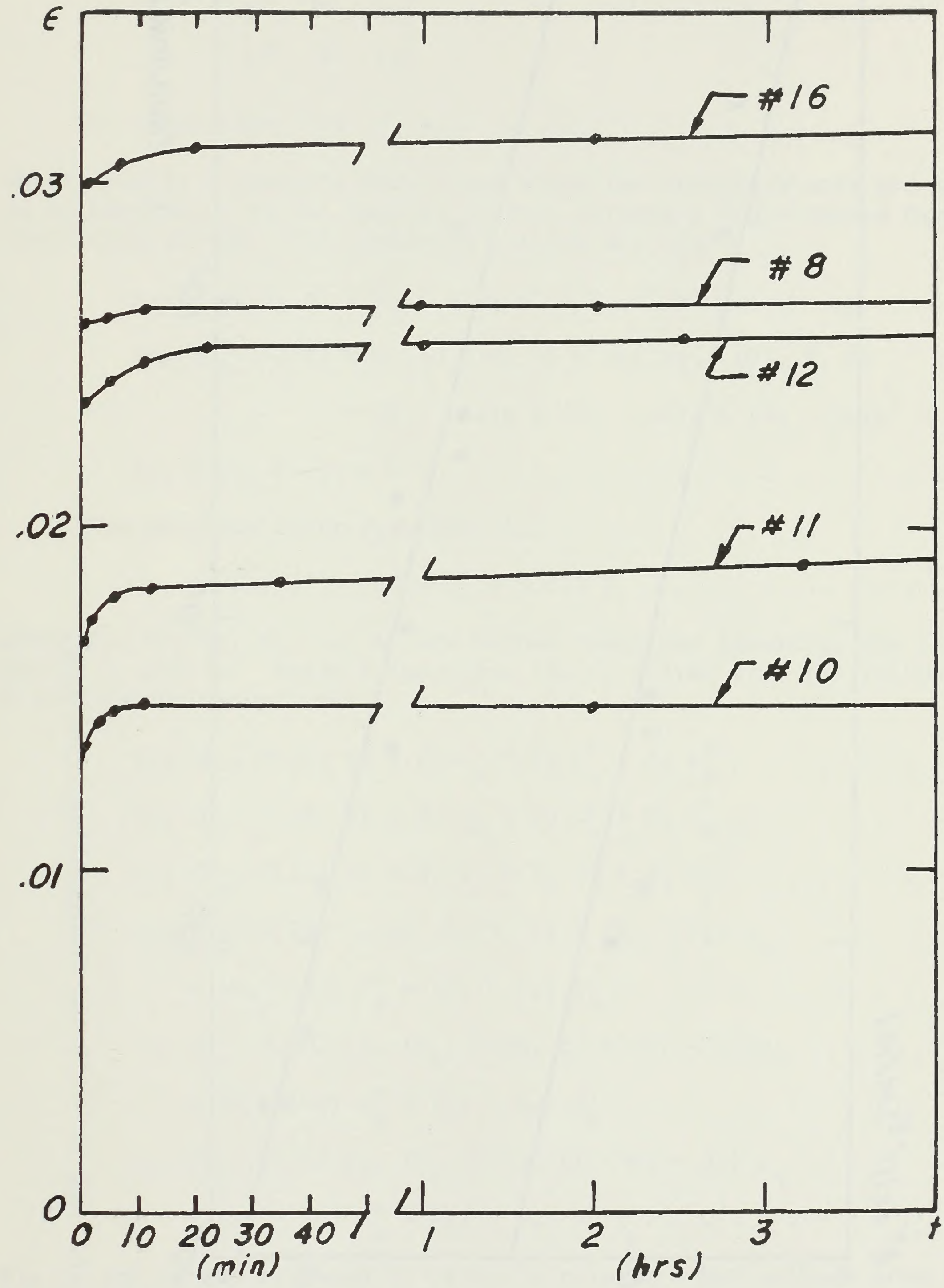

Fig. 1. Longitudinal Strain vs. Time.

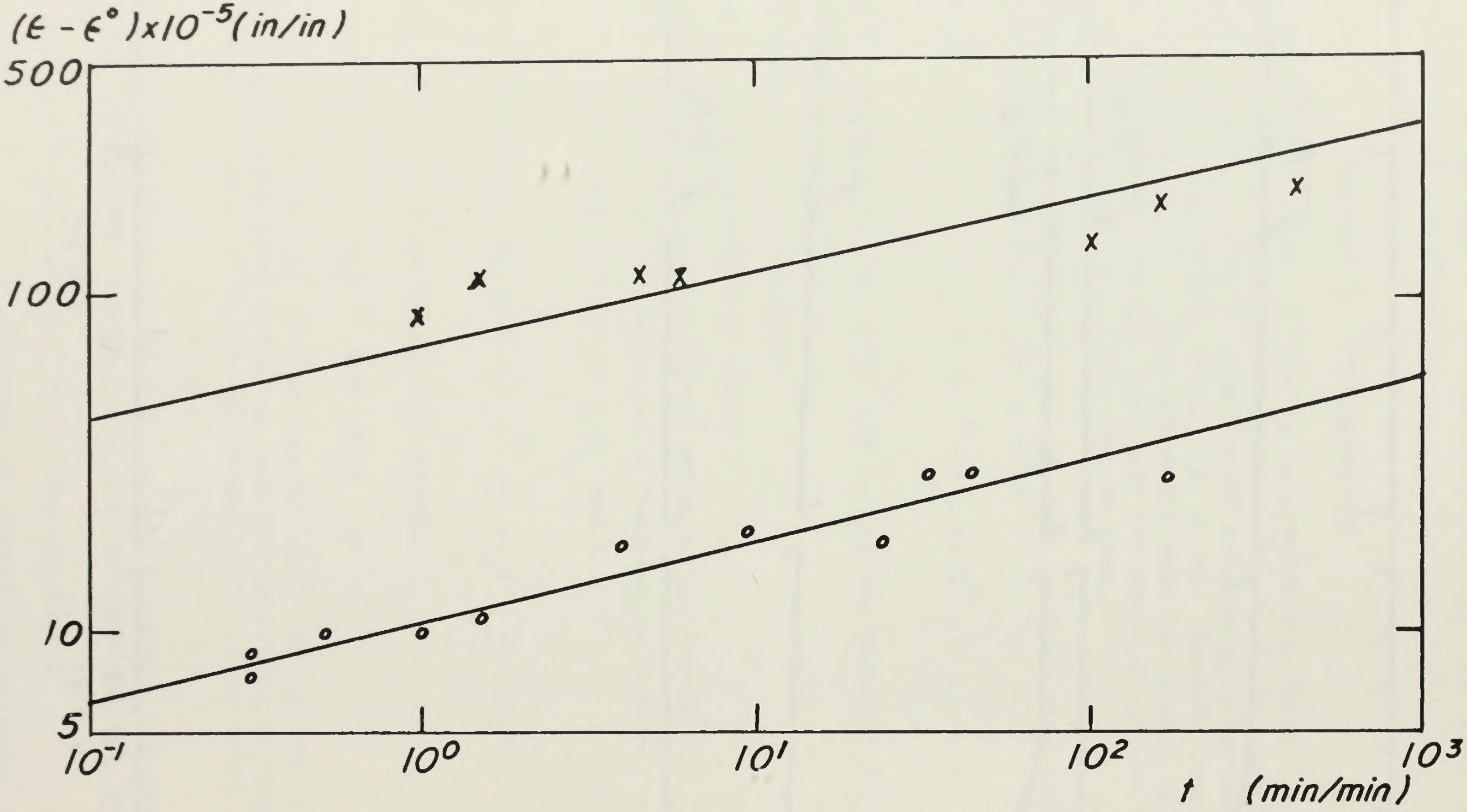

Fig. 2. Log (ε - $\varepsilon°$) vs. Nondimensionalized Time.

$$[\sigma] = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & \sigma_3 \end{bmatrix} \tag{3}$$

For simplicity, let $\sigma_3 = \sigma$ . . . . (4)

where axis 1, 2 indicate directions along the bedding planes and axis 3 is perpendicular to the bedding planes, forming a right-handed Cartesian coordinate system. The nonlinear strains are (8)

$$\varepsilon_{33}\ (O_c, S, t) = F_1\,\sigma + F_2\,\sigma^2 + F_3\,\sigma^3$$

$$\varepsilon_{22}\ (O_c, S, t) = \varepsilon_{11}(O_c, S, t) = \nu_{31}\,\varepsilon_{33}\ (O_c, S, t)$$

$$= (F_1 - G_1)\sigma + (F_2 - G_3)\sigma^2 + (F_3 - G_4)\sigma^3$$

$$\varepsilon_{32} = \varepsilon_{31} = \varepsilon_{21} = 0 \tag{5}$$

From previous investigations (4),

$$\nu_{31} = -0.2747 + 1.162\ O_c + 0.642\ S \tag{6}$$

where F_1, F_2, F_3, G_1, G_3, G_4 are kernel functions involving the variables O_c and t. These 6 functions can be solved from the following 6 simultaneous equations:

$$\varepsilon_{33}\ (O_c, 0.25, t) = F_1\,\sigma_a + F_2\,\sigma_a^2 + F_3\,\sigma_a^3 \tag{7}$$

$$\varepsilon_{33}\ (O_c, 0.50, t) = F_1\,\sigma_b + F_2\,\sigma_b^2 + F_3\,\sigma_b^3 \tag{8}$$

$$\varepsilon_{33}\ (O_c, 0.75, t) = F_1\,\sigma_c + F_2\,\sigma_c^2 + F_3\,\sigma_c^3 \tag{9}$$

$$\nu_{31}\ (O_c, 0.25)\ \varepsilon_{33}(O_c\ 0.25, t) = (F_1 - G_1)\ \sigma_a + (F_2 - G_3)\ \sigma_a^2 + (F_3 - G_4)\ \sigma_a^3 \tag{10}$$

$$\nu_{31}\ (O_c, 0.50)\ \varepsilon_{33}\ (O_c, 0.50, t) = (F_1 - G_1)\sigma_b + (F_2 - G_3)\ \sigma_b^2 + (F_3 - G_4)\ \sigma_b^3 \tag{11}$$

$$\nu_{31}\ (O_c, 0.75)\ \varepsilon_{33}\ (O_c, 0.75, t) = (F_1 - G_1)\ \sigma_c + (F_2 - G_3)\ \sigma_c^2 + (F_3 - G_4)\ \sigma_c^3 \tag{12}$$

F_1, F_2 and F_3 can be found by Cramer's rule or other methods from Eqs. 7 to 9, whereas, G_1, G_3 and G_4 can be solved from Eqs. 10 to 12. Subscripts a, b, and c correspond to stress levels of 0.25, 0.50 and 0.75

respectively. Once these 6 kernels are found, the complete time history of the strains are (8)

$$\varepsilon_{33}\,(0_c,\ S,\ t) = \int_o^t F_1\,\dot{\sigma}\,(\zeta_1)\,d\zeta_1 + \int_o^t\!\int_o^t F_2\,\dot{\sigma}\,(\zeta_1)\,\dot{\sigma}\,(\zeta_2)\,d\zeta_1\,d\zeta_2 + \int_o^t\!\int_o^t\!\int_o^t F_3\,\dot{\sigma}\,(\zeta_1)\,\dot{\sigma}\,(\zeta_2)\,\dot{\sigma}\,(\zeta_3)\,d\zeta_1\,d\zeta_2\,d\zeta_3 \tag{13}$$

$$\varepsilon_{22}\,(0_c,\ S,\ t) = \varepsilon_{11}(0_c,\ S,\ t) = \int_o^t (F_1 - G_1)\,\dot{\sigma}\,(\zeta_1)\,d\zeta_1 + \int_o^t\!\int_o^t [(F_2 - G_3)\,\dot{\sigma}\,(\zeta_1)\,\dot{\sigma}\,(\zeta_2)]\,d\zeta_1\,d\zeta_2 + \int_o^t\!\int_o^t\!\int_o^t [(F_3 - G_4)\,\dot{\sigma}\,(\zeta_1)\,\dot{\sigma}\,(\zeta_2)\,\dot{\sigma}\,(\zeta_3)] \times d\zeta_1\,d\zeta_2\,d\zeta_3 \tag{14}$$

$$\varepsilon_{32} = \varepsilon_{31} = \varepsilon_{21} = 0 \tag{15}$$

ζ_1, ζ_2, ζ_3 are dummy variables.

EXPERIMENTAL PROCEDURE

Sample Preparation

One of the main difficulties in mechanical testing of an oil shale is the preparation of samples. Conventionally, all the oil shale samples were cut mechanically by diamond saw blades and cores. To avoid any micro-cracks in the samples produced by cutting, a wire saw with diamond impregnated wire was used. The wire saw cuts smoothly and accurately, with a minimum loss of kerf.

Since oil shale is a stratified rock, care was taken to select as uniform samples as possible. Layers of obviously foreign composition, major elastic inclusions, and locations where faults existed were avoided. The set of 3 to 4 duplicate oil shale samples required for creep testing, obtained by exploiting the lateral uniformity of oil shale, were cut from a single horizontal (3.175 cm. thick) layer from a core of the upper Green River Formation. The test sets were selected with different oil yields. The size of each specimen used for creep testing was 1.27 cm. square in cross-sectional area and 3.175 cm. long.

Instrumentation

Prior to creep testing, a Tinius Olsen universal testing machine was used to determine the ultimate compressive strength of the material of the same horizon as the materials to be tested for creep.

For creep tests, specimens were placed between spherical seat and the fixed plate of the creep frame. The creep machine, (Fig. 3) consists of a Conbel Model 355 testing machine, pneumatic driven. Dial gages readable to 0.00254 mm (.0001") were used to measure the displacement of the specimens.

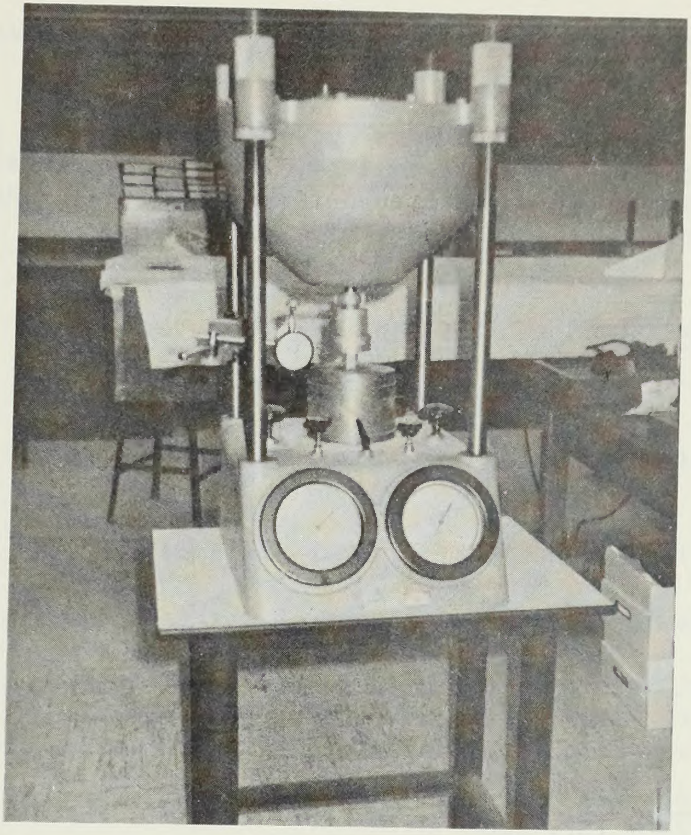

Figure 3. Creep Machine

Three to four duplicate samples were tested with various loads, ranging from 25% through 75% of the ultimate compressive strength of the material in the layer. In this manner, the stress effect can be determined on the specimens of the same oil and mineral content. Specimens were placed between spherical seat and fixed plate of the creep frame. The spherical seat resting on a lubricated socket was used to insure a uniform contact pressure during testing. An initial load of approximately 890 N (200 pounds) was applied to check for eccentricity and for specimen alignment. The exact load applied to the specimen was read from the dial gage of the creep machine which was calibrated before it was used as a loading device. Also, a dial gage readable to 0.00254 mm (0.0001") was placed between a fixed bar and the spherical seat, and the air was introduced slightly, just enough to set the dial gage into motion. At this instant, the exact dial reading was taken. The load was then increased to full load and maintained throughout the testing by an air pump.

Prior to creep testing, the specimens were surface-dried, weighed, measured, and then placed in the creep frame for testing. The vertical displacement of the specimen was measured after the initial load was applied and also when the full load was applied. The time interval for measuring the displacement depended on the displacement rate of the specimen tested.

Due to the small displacements, great precaution was taken in measuring them. Typical data of creep strain versus time is shown in Fig. 1. It shows the creep behavior with an initial non-linear range and gradually assumes a constant strain rate.

TEST RESULTS AND THEIR STATISTICAL ANALYSIS

Data

The following variables were found significant in the statistical analysis:

O_c = organic content in fraction by volume; and

S = stress level as a percentage of ultimate compressive stress.

From the oil yield values M in gallons per ton (1 gallon/ton = 4.19 cm^3/kg) determined by Fischer Assay, the organic content in fraction by volume, O_c, was calculated using the relation derived by Smtih (10):

$$O_c = \frac{157.76M}{(0.957M + 107)\ 100} \quad \ldots\ldots\ldots \quad (16)$$

Statistical Analysis

From the raw data, it was found that n varied linearly with respect to O_c and S (Figs. 4, 5); that ε^+ varied linearly with O_c and parabolically with S (Figs. 6, 7); that ε° varied parabolically with O_c but linearly with S (Figs. 8, 9). Thus the form of the regressional equations was determined.

Based on regressional analysis, the following equations were obtained which relate the mechanical properties n, ε^+, and ε° from Eq. (1) with the organic contents and stress levels:

$$n = 0.2801 - 0.8245\ O_c - 0.1750\ S + 1.5827\ O_c\ S \quad \ldots\ldots\ldots \quad (17)$$

Coefficient of determination, $r^2 = 0.7440$
Number of samples, $N = 13$
Standard error of estimate, $s = 0.0286$

Mean values, $\bar{n} = 0.1736$
$\bar{O}_c = 0.1870$
$\bar{S} = 0.4808$

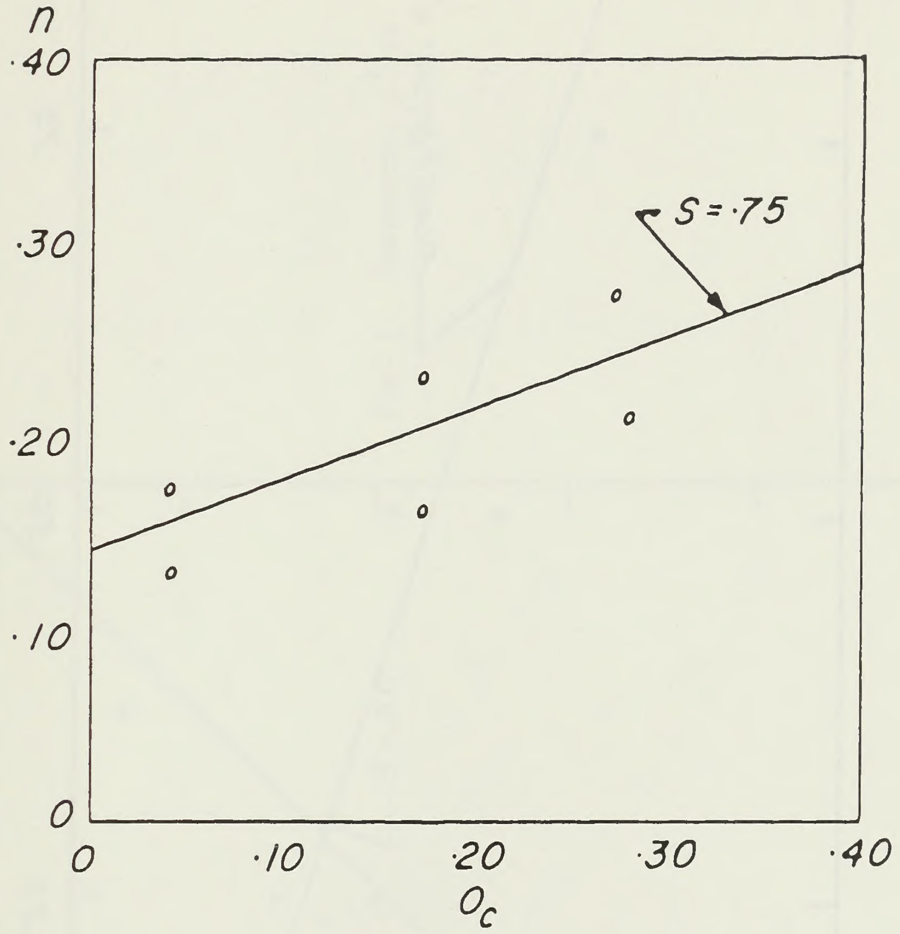

Fig. 4. Parameter, n vs Organic Volume, O_c.

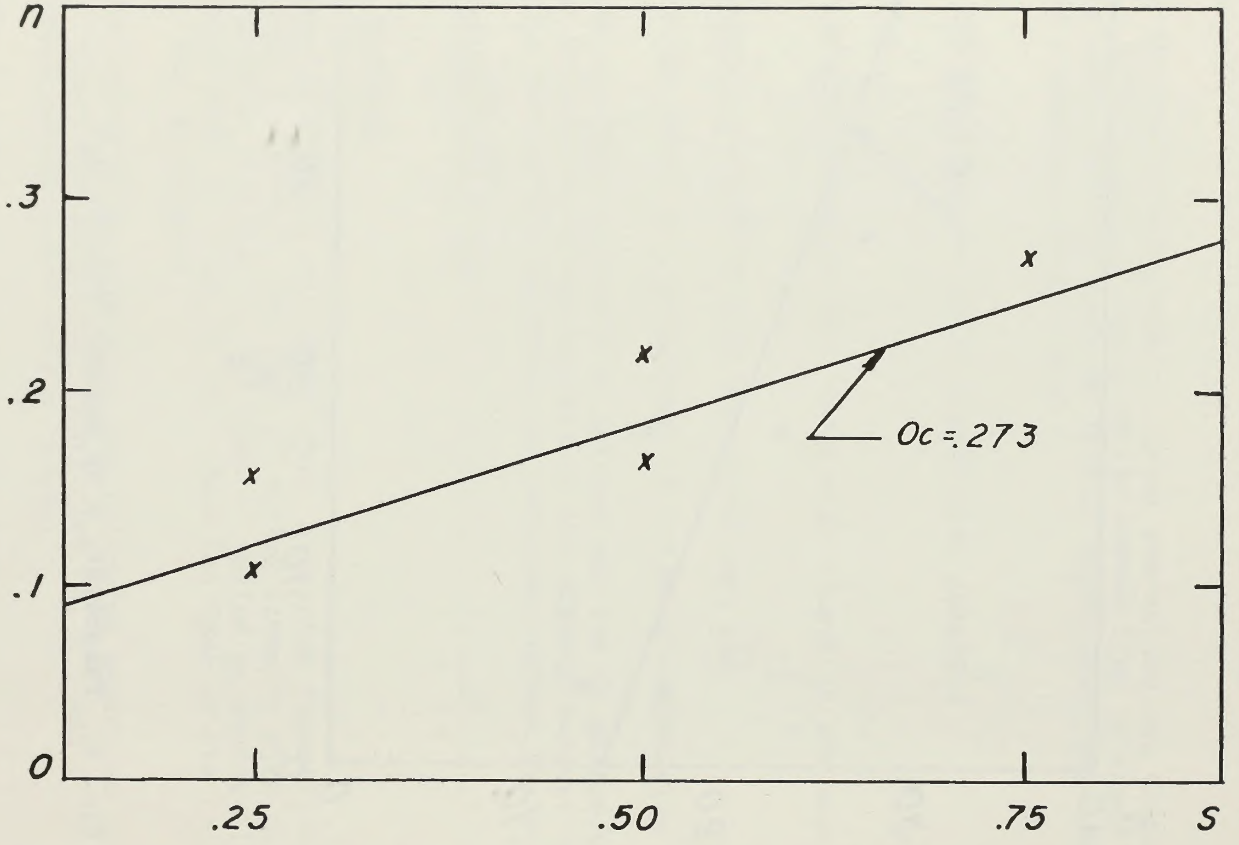

Fig. 5. Parameter, n vs Stress Level, S.

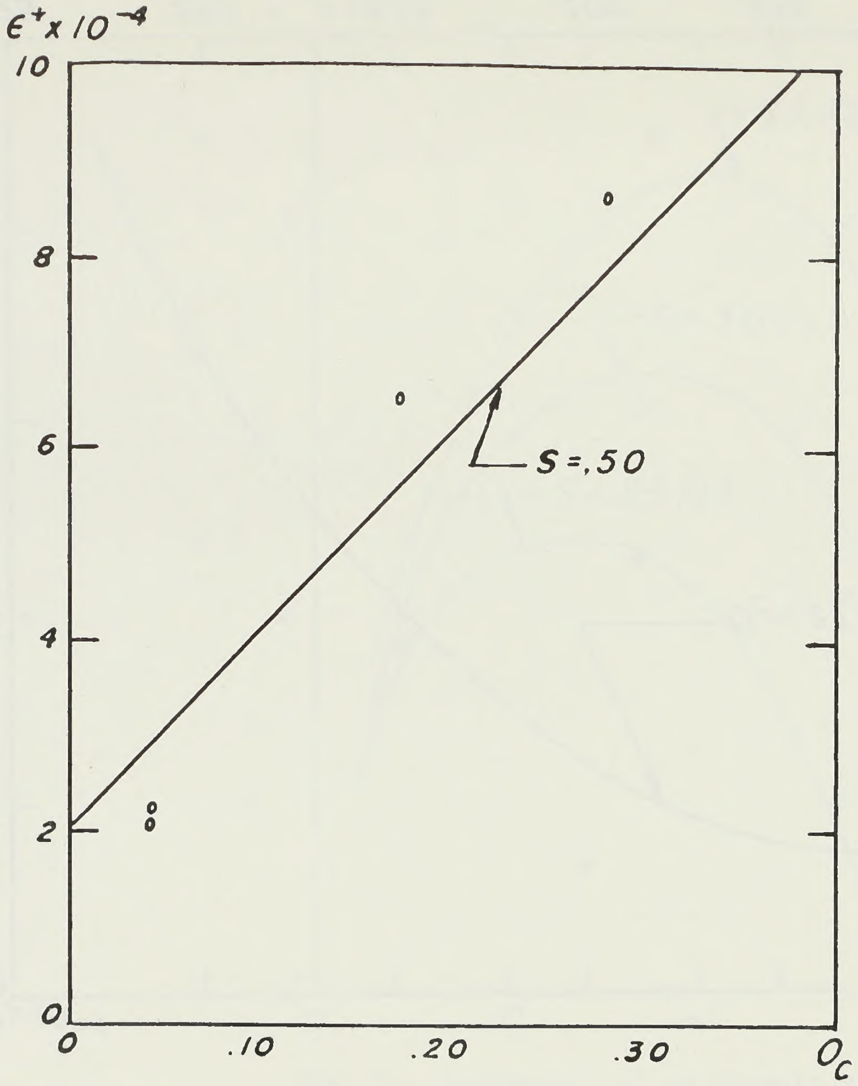

Fig. 6. Parameter, ε^+ vs Organic Volume, O_c

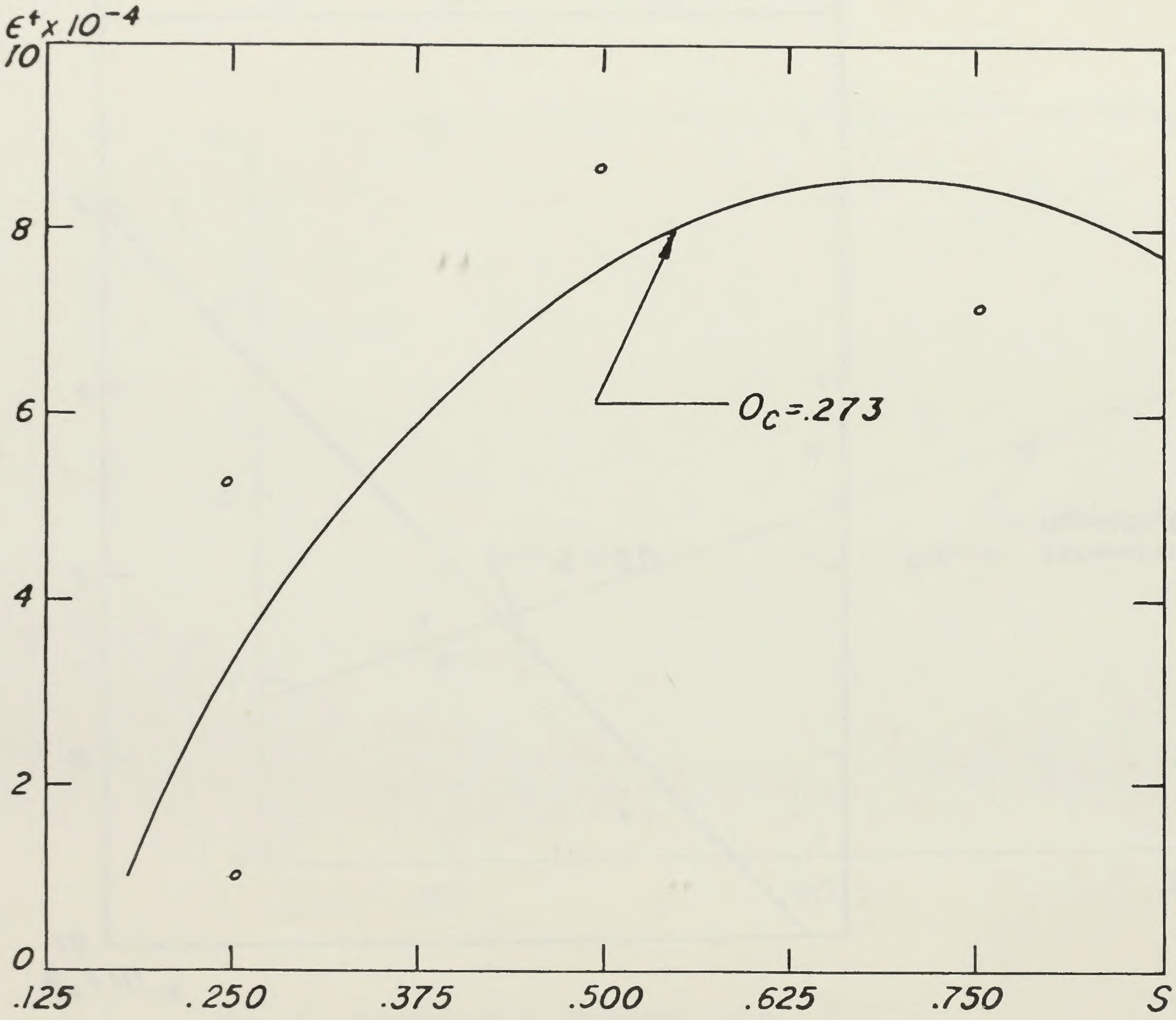

Fig. 7. Parameter, ε^{+} vs Stress Level, S.

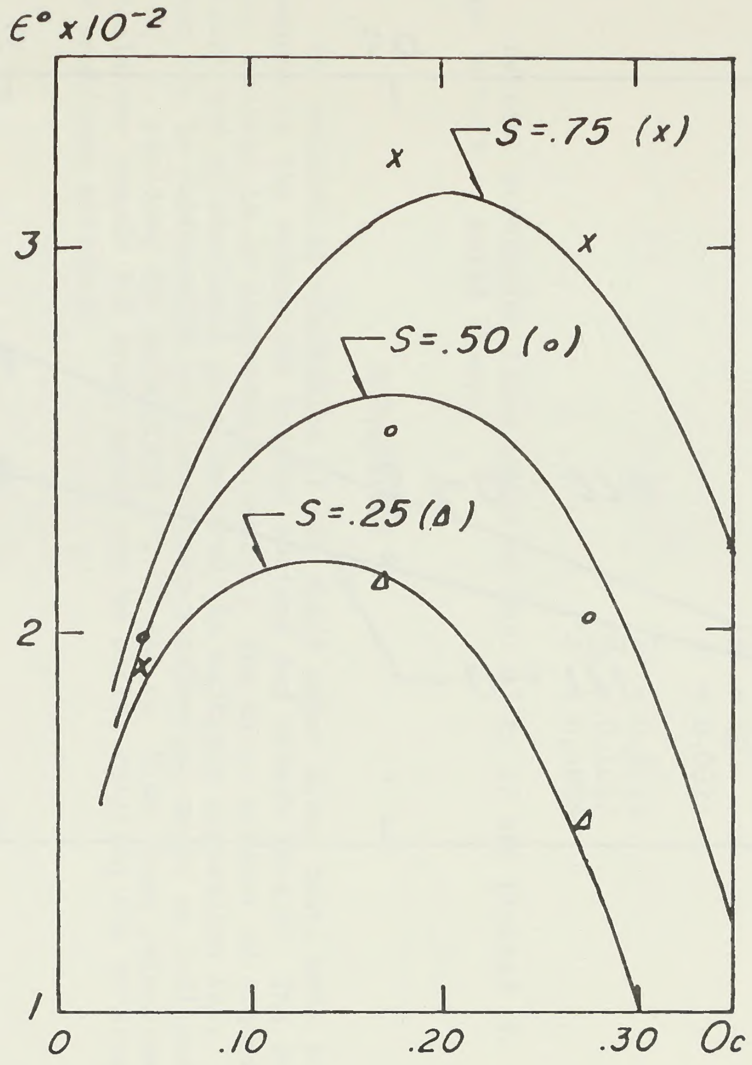

Fig. 8. Parameter, ε° vs Organic Volume O_c.

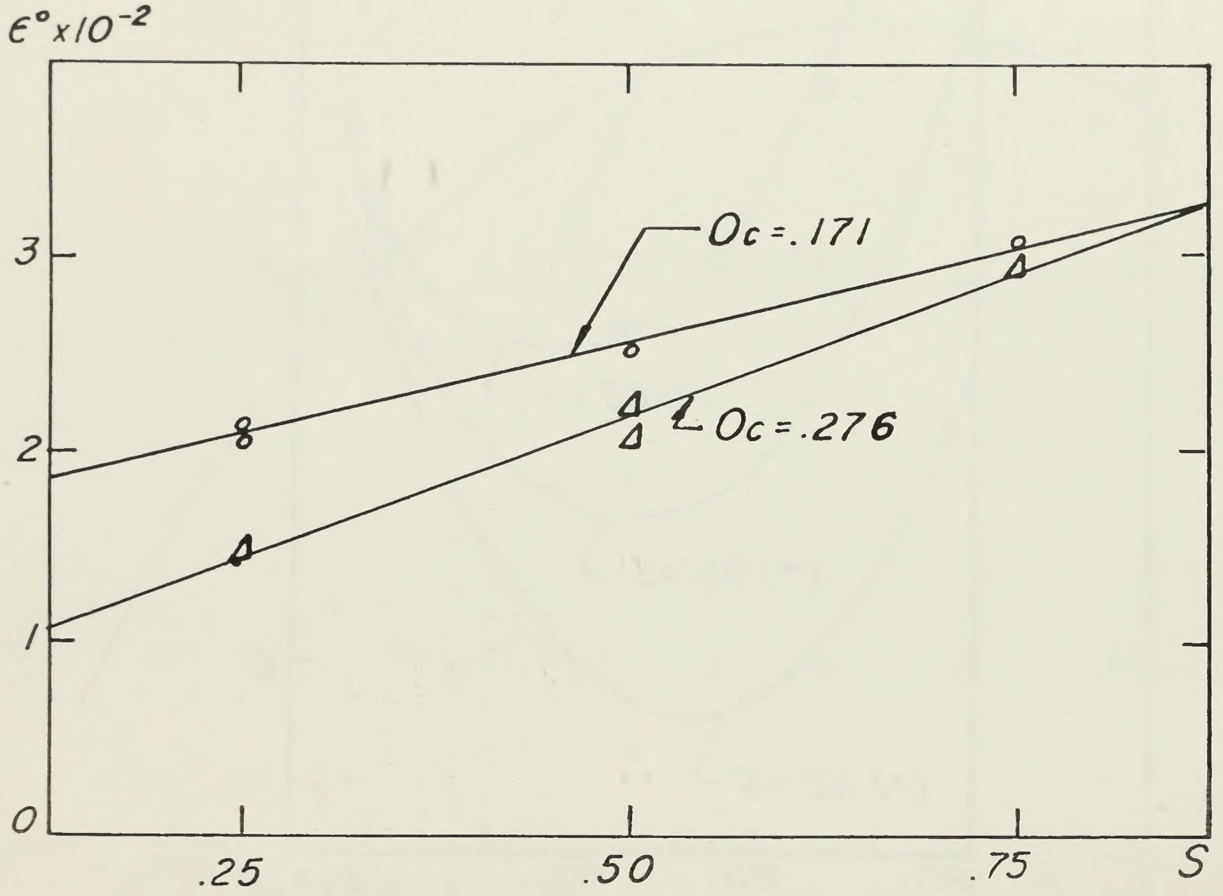

Fig. 9. Parameter, ε° vs Stress Level, S.

$$\varepsilon^{+} = -0.0005 + 0.0027S + 0.0004\ O_c - 0.0026S^2 + 0.0034\ O_cS \qquad (18)$$

$r^2 = 0.8383$
$N = 13$
$s = 0.0001$

$\bar{\varepsilon}^{+} = 0.0004$
$\bar{O}_c = 0.1612$
$\bar{S} = 0.4808$

$$\varepsilon^{\circ} = 0.0141 + 0.0885\ O_c - 0.4130\ O_c^2 + 0.1085\ O_cS. . . . . \qquad (19)$$

$r^2 = 0.8462$
$N = 12$
$s = 0.0023$

$\bar{\varepsilon}^{\circ} = 0.0225$
$\bar{O}_c = 0.1627$
$\bar{S} = 0.4808$

Typical prediction lines based on Eqs. 17 to 19 are plotted in Figs. 4 to 9 as solid lines.

CONCLUSIONS

The mechanical properties of oil shale under creep tests were influenced by the volumetric organic content and stress levels. The organic content is an important parameter. The cross product of organic content and stress level also improved the multiple regression fit. The creep can be represented by a nonlinear-strain-time model as indicated by Eq. 1, yielding the parameters ε°, ε^{+} and n. From these parameters, a nonlinear pseudo 3-D creep model can be built, relating the strains to the nonlinear stresses.

REFERENCES CITED

1. Bland, D. R., The Theory of Linear Viscoelasticity, Pergamon Press, Oxford, 1960.

2. Chong, K. P., Smith, J. W., Chang, B., Hoyt, P. M., and Carpenter, H. C., "Characterization of Oil Shale and Uniaxial Compression," Proceedings of the 17th U. S. Symposium on Rock Mechanics, Universsity of Utah, August, 1976, 8 pp.

3. Chong, K. P., Smith, J. W., Roine, S. and Chang, B., "Mechanical Properties of Oil Shale by 'Modified' Split Cylinder Testing," Proceedings of the 18th U. S. Symposium on Rock Mechanics, Colorado School of Mines, Golden, CO, June, 1977, 5 pp.

4. Chong, K. P., Turner, J. P., and Dana, G. F., "Mechanical Characterization of Utah Oil Shale," Report of Investigations, U. S. Dept. of Energy, to appear.

5. Christensen, R. M., Theory of Viscoelasticity, Academic Press, New York, 1971.

6. Courant, R., and Hilbert, D., Methods of Mathematical Physics, Vol. I, Interscience Publishers, Inc., New York, 1966.

7. Dana, G. F., and Smith, J. W., "Oil Yields and Stratigraphy of the Green River Formation's Tipton Member at Bureau of Mines Sites near Green River, Wyoming," Report of Investigations 7681, Laramie Energy Research Center, Laramie, WY, 1972.

8. Findley, W. N., Lai, J. W., and Onaran, K., Creep and Relaxation of Nonlinear Viscoelastic Materials, North-Holland Publishing Co., 1976.

9. Fung, Y. C., Foundations of Solid Mechanics, Prentice-Hall, Inc., Englewood Cliffs, 1965.

10. Smith, J. W., "Relationship Between Rock Density and Volume of Organic Matter in Oil Shales," Report of Investigations, LERC/RI-76/6, Laramie, WY, 1976.

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